The NOAA Depolarization and Backscatter Unattended Lidar System: A Review of Arctic and Tropical Cloud Observations

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ABSTRACT

The NOAA Depolarization and Backscatter Unattended Lidar (DABUL) system has been successfully gathering atmospheric data from all over the world since 1996. This lidar system has been deployed in environmental conditions ranging from wintertime in the Arctic to summertime in the tropics. Although the wide spectrum of conditions brought to light invariable engineering adjustments, the DABUL system has provided invaluable, time-continuous measurements on a variety of cloud and aerosol scenarios. In this paper we report on the major experiments in which cloud data sets were obtained with the DABUL system. These include an annual cycle of cloud statistics from the Arctic and high-altitude cirrus observed in the tropics.

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1. Introduction

The Depolarization and Backscatter Unattended Lidar (DABUL), developed at NOAA's Environmental Technology Laboratory (ETL), was designed to operate unattended in any environment to obtain continuous profiles of atmospheric backscatter and depolarization ratio. This system has been successfully deployed since 1996 providing range-resolved information on clouds and aerosols.

DABUL operates at a wavelength of 523 nm. Typically the pulse energy of the laser is 40 µJ inside of the DABUL unit but is reduced to 25 µJ due to losses by the time it exits from the top of the container (Grund and Sandberg 1996). The combination of low laser pulse energies (micropulse) and a large beam diameter makes the DABUL system fully eye-safe (Alvarez et al. 1998). By employing high pulse rates (adjustable up to 2000 Hz) and time-averaging (typically 5 s) adequate Signal to Noise Ratio is easily obtained throughout the entire troposphere. The pulse length is 10 ns, but photo-counts are accumulated for 200 ns intervals resulting in a range resolution of 30 m. Signal is recorded out to a maximum range of 60 km.

The DABUL optics are housed in a weatherproof container that is environmentally controlled for the temperature and humidity of the optics and electronics. This lidar can be statically mounted for vertically staring data or, if it is coupled with a specifically designed cradle, can scan in a single vertical plane up to 100 degrees on either side of zenith for full horizon-to-horizon measurement capability.

DABUL specifications are summarized in Table 1 and additional system information can be found at: http://www2.etl.noaa.gov/DABUL.html.

TABLE 1. The ETL DABUL system specifications.

Laser wavelength	523 nm
Laser energy	40 micro-Joules
Repetition rate / Averaging time	2000 Hz / 1s
Range resolution / max range	30 m / 60 km
Transmit beam diameter, Div.	0.3 m, 25 microrads
Receiving Field of View's	100, 640 microrads
Detection / Detector	Photon Count/PMT
Weight (without scanner)	375 kg
Size (without scanner)	1m (w), 1.5 m (l), 2.3m (h)

One of the important features of the DABUL system is the depolarization ratio information which provides an assessment of an atmospheric particles' phase. In general terms, if an incident electric field is linearly polarized then the radiation scattered into either the forward or backward direction has the same polarization as the incoming wave, and no depolarization occurs. Spherically symmetric particles backscatter energy through a combination of axial reflections and/or surface waves which do not change the incident polarization state, whereas the backscatter from complicated shapes (ice crystals) induce internal reflections that rotate the incident polarization state resulting in **de**polarization. In this manner lidar measurements of atmospheric depolarization have been commonly used for distinguishing between the liquid and solid phases of water in the atmosphere.

The depolarization ratio is defined as the ratio of the intensity of the received or backscattered light polarized perpendicular to the direction of the transmitted polarization divided by the intensity of the backscattered light polarized the same as the transmitted polarization. Small raindrops, water cloud droplets, and fog are considered spherical atmospheric particles and have depolarization ratios that are close to 0%. Non-spherical particles such as ice crystals, snowflakes or large oblate raindrops contain a cross-polarized component produced by internal reflections and refractions and can exhibit depolarization ratios greater than 20-30%.

It is important to note that no change in the polarization state between the scattered and incoming radiation does not necessarily imply that the scatterers are spherical. This can also be a result of scattering from certain crystal shapes and orientations that have reflectional symmetry. For example, oriented ice crystals such as plates can specularly reflect laser light thus producing small depolarization ratios that might be misinterpreted as water cloud. For this reason, the lidar was tilted 5 degrees off-vertical during SHEBA to prevent ambiguous depolarization signatures.

Determining the cloud layers from DABUL data, reported in the sections below, is a fairly straightforward processing step. After the necessary instrument corrections are applied to the data, the intensity, depolarization ratio, or both fields of the data were thresholded to determine cloud base and top heights for as many layers of cloud that are detected. The most commonly used fields are the parallel intensity and the depolarization fields since the SNR is greatest. After the cloud layer boundaries are determined, the average returned power and the signal-weighted average value of the depolarization ratio for that layer are calculated.

2. DABUL Cloud Observations and Results

a. Arctic Cloud Climatologies

Characterizing Arctic cloud geometric and microphysical properties over the Arctic region is a critical step towards understanding their radiative impact on the surface. In order to understand cloud-radiative feedback mechanisms, cloud properties such as fraction, vertical distribution, particle phase and size are required. However, obtaining comprehensive measurements in the Arctic has been historically challenging, and, as a consequence, very little long-term observational data exist on the properties of Arctic clouds, most especially during the dark winter season. Clouds that occur during the polar wintertime and transition seasons, as well as the occurrence of mixed-phase clouds in these seasons, remain one of the least documented yet critically important pieces of information for characterizing and understanding the radiative feedbacks in the Arctic (Curry et al. 1996).

An Arctic cloud climatology of occurrence and phase was obtained by the DABUL system, which was deployed on board an icebreaker frozen and drifting with the sea ice for one year. These data were obtained as part of the Surface Heat Budget of the Arctic Ocean (SHEBA) program, an international, interdisciplinary, and multi-agency program led by the National Science Foundation (NSF), designed to investigate and characterize the Arctic's oceanic, atmospheric, and ice properties over an entire annual cycle (Moritz et al. 1993). The SHEBA ice camp drifted along a path from 143 W and 75 N to 166 W and 79 N, translating into a 2800 km drift and a 770 km displacement for the one-year period. DABUL was operational from 1 November 1997 through 8 August 1998, after which laser failure precluded gathering any further data. Only two major down-times are reportable; 2 - 12 February (for heater repair) and 5 - 10 July (for shutter disabling).

The two most important products that resulted from the DABUL measurements include the annual cycles of cloud and liquid water phase occurrence. In this one-year observational study, clouds were prevalent ~80 % of the time with the greatest occurrences and lowest bases present during the summer season. The polar dark season, up until now wholly undocumented, showed an average cloud amount of approximately 65%.

DABUL's unique capability of measuring depolarization ratios significantly adds to the value of the cloud boundary information. With this data set, we now can evaluate how often water phase occurs, as well as assessing if exist relationships exist between height and temperature with phase (Intrieri et al. 1999). Characterizing the correct phase of a cloud is perhaps one of the most critical parameters for correctly modeling clouds and their radiative impact on the surface (Sun and Shine, 1994). Lidar depolarization data yields information on the shape of the scatterers in the volume, indicating the occurrence of ice versus water phase in the column.

This information was used to determine the occurrence of liquid water phase. The frequency of occurrence of ice is not presented since it can be biased low due to attenuation caused by water.

In general, the lidar detected water phase (sometimes even in multiple layers) throughout the entire polar winter, spring, and summer seasons. Although the occurrence of water cloud was much greater in the summer (97%) than the winter months, the lidar observed water/mixed phase ~45% of the time that cloud was present during the winter season (Fig. 2). The springtime measurements revealed clouds with liquid water present 73% of the time cloud was observed. Figure 2 also illustrates the amount of time the lidar signal was completely attenuated when compared to radar cloud top signal over the course of the year. Note that in November and January complete attenuation occurred for a greater percentage of the time than liquid water detected. This is due to snow storm events in which the signal within the precipitation was lost but no water detected. The remaining months of the year show that liquid water does not always cause the signal to dissipate and indicates that lidar can also penetrate layers containing water in the Arctic.

Perhaps the most significant DABUL result is documentation of the high percentages of water phase occurrence present even during the coldest, darkest winter months; detected ~45% of the time cloud was present, up to heights of 6 km and down to temperatures as low as -34 C.

The full DABUL Arctic cloud data set and case studies from SHEBA can be viewed at; http://www.joss.ucar.edu/cgi-bin/codiac/projs?SHEBA and http://www6.etl.noaa.gov/projects/fireace.html.

b. Tropical Cirrus

Clouds are critical regulators of climate and weather. Understanding their radiative impact is challenging on any scale and over any region. For example, although the tropical western Pacific is known to be a source of energy on a planetary scale, the specifics of this heat engine are not well understood. The Nauru 99 field program was designed to obtain measurements on the radiant heat transfer and the effects of clouds on ocean weather processes in the tropics through measurements over land, in air, and under the ocean with a variety of instrumentation. The platform for the ocean-based NAURU 99 ship measurements was the NOAA's Ronald H. Brown.

One of the many specialized instruments aboard the Brown was the DABUL system. The lidar was on-loaded in early June for the 1 month-long intensive campaign designed to make observations in the vicinity of Nauru Island. The lidar obtained 20 days of data between June 11 and 26 and July 12 through 15. Laser failure was the cause of the measurement gap between June 27 and July 11, the first available opportunity for a crew change which afforded the parts swap. However, even with the interruption, this data set reveals many cloud scenarios including boundary layer water clouds; mid-level, mixed-phase cloud systems with precipitation; and high-altitude ice phase cirrus clouds (Fig. 3) which were often not visible by eye.

By utilizing both the lidar returned power and the depolarization fields, cloud boundary determination is significantly enhanced especially for the high altitude cirrus. Additionally precipitation can most often be included or not since the phase and power can be used to discriminate it from cloud. For the times DABUL was operating, clouds were detected 46% of the time, with clouds displaying a bimodal distribution in the vertical predominantly occurring below 1500 m and above 8000 m. All of the cloud measurements from DABUL during the NAURU experiment can be viewed at; http://www2.etl.noaa.gov/lidar_img/nauru_june.html.

3. Future Work and Summary

The DABUL Arctic and tropical measurements hold a wealth of information that continues to be tapped. Combining these lidar data with other supporting instruments is the key to understanding clouds' comprehensive radiative effects both at the top of the atmosphere and at the surface. Additionally, we intend to explore lidar-radar retrieval techniques with the DABUL such as those developed to infer cloud microphysical and optical properties using the ETL IR lidar system.

Aerosol research is another area of upcoming development as several future experiments are being pursued. Additionally, a second version of DABUL is currently under development and construction which will be placed permanently at the Mauna Loa observatory for cloud characterization and aerosol measurements.

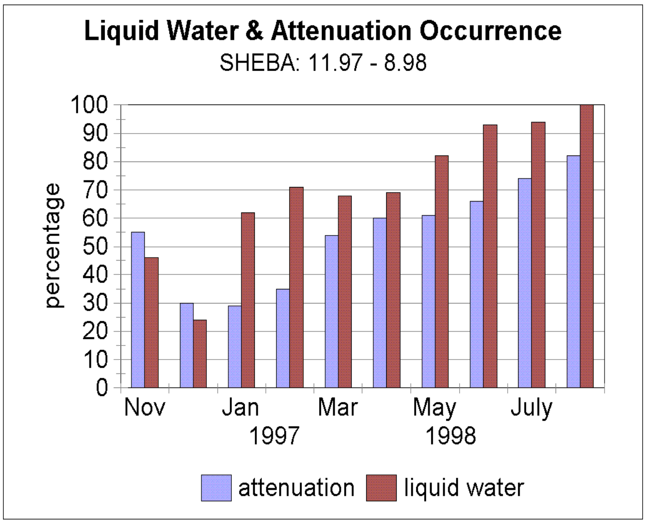

FIG. 1: Lidar-derived monthly-averaged cloud occurrence percentages (top) and liquid water and attenuation occurrence percentages (bottom) for the SHEBA experiment.

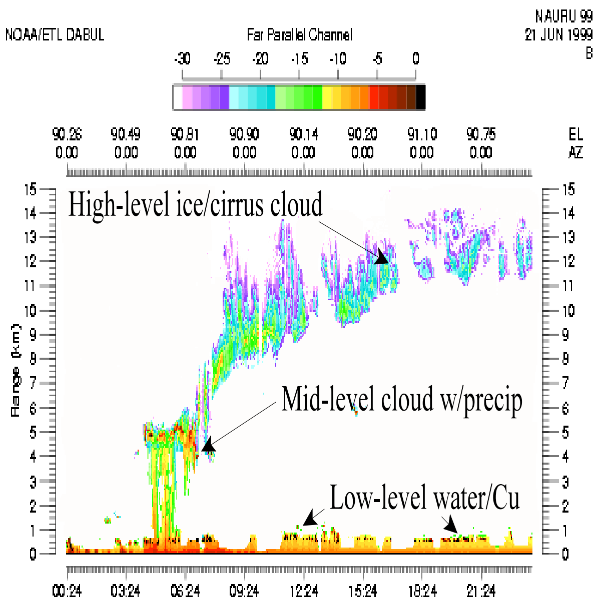

FIG. 2 : A 24 hr time-height plot of DABUL returned power measurements from the NAURU experiment illustrating the spectrum of atmospheric returns observed.

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